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LANL

Backpack Laser Induced Breakdown Spectroscopy

Atomic Emission Analysis System

User's Manual

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LASER SAFETY

The backpack LIBS system contains an embedded Class IV laser system and is therefore classified as a Class I device per internal communication from the Los Alamos National Laboratory Laser Safety Officer.

The user must read this manual before operating the backpack LIBS system. Before operating this equipment, refer to ANSI Standard Z136.1, which outlines precautions for the safe operation of laser equipment and specifically recommends that:

1. All users should have an initial eye examination prior to operating laser equipment, followed by periodic re-examination.
2. Users should always use appropriate eye protection when operating laser equipment. However, since this device is operated as a Class I device under normal use, no eyewear is necessary. The user should be aware that this system does contain ***an invisible Class IV laser that can cause permanent skin and eye damage up to and including complete loss of vision***. Therefore, it is important that all precautions should be taken to protect anyone in the area of use from being exposed to the laser beam.
3. Engineering controls and interlocks, both software and hardware, have also been integrated into the LIBS system for the user's safety. Therefore, if the LIBS system is used properly, it is extremely difficult for personnel using or others in proximity to this system to be exposed to the laser beam, which could cause damage to the eyes or skin.

CAUTION

Never observe the beam from a Class IV laser without using the proper eyewear. For proper eyewear, refer to ANSI Standard Z136.1 or contact personnel from Los Alamos National Laboratory responsible for the development of this laser analysis system. Also, ***never attempt to observe the microplasma generated by the focused laser beam without the proper eyewear***. For proper eyewear, contact James E. Barefield II @ 505-665-5195 or jbarefield@lanl.gov or the LANL Laser Safety Officer.

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Introduction

The backpack LIBS (Laser Induced Breakdown Spectroscopy) system is designed to provide rapid, in-field, elemental analysis of environmental samples important to the safeguarding of special nuclear materials. Currently, environmental elemental analysis is performed by collection, packaging, and shipping of samples to an approved analytical laboratory for analysis. This practice can take days to months, if not longer, to complete and is also costly, especially if some of the samples are contaminated with actinide elements.

The backpack LIBS system is designed to be user friendly, with several integrated safety features making the system safe to operate under normal conditions. Operators should be aware that this system contains a Class IV embedded laser. Since safety interlock features, both software and hardware, have been integrated into the system, no laser safety eyewear is required. Depending upon the intended use and analysis scenario, most analyses can be completed in a matter of minutes.

The complete system is operated from battery power in a standalone mode and weighs approximately 25 pounds. The nominal operational lifetime of the backpack LIBS system is approximately 3.5 hours.

Theory of Operation

Laser Induced Breakdown Spectroscopy (LIBS) is a laser-based optical method that can be used to determine the elemental composition of liquids, solids, and gases. In the LIBS technique, short pulses (typically 10 nanoseconds) from a laser are focused upon the surface of a sample, generating a microplasma. The microplasma consists of elements evolved from the surface and the gas above the surface. The emission from the plasma is wavelength resolved and detected using a dispersive device and a detector. The resulting spectrum is analyzed with a computer. The emission spectrum is characteristic of the emitting species in the plasma, which are typically atoms, ions, and small molecules. If the spectra are collected and analyzed as a function of the chemical composition of the elements present, calibration curves can be generated from which semi to quantitative information can be determined.

LIBS offers several advantages over classical wet chemical analysis techniques: (1) it provides real-time or near-real-time automated elemental analysis, (2) it is essentially non-destructive with little or no sample preparation and handling required, and (3) all the elements in the periodic table can be analyzed from hydrogen to heavy elements such as the actinides. It is also a highly configurable technique, meaning that instruments of many different shapes, sizes, and configurations can be designed, constructed, tested, and used to obtain chemical compositional information with varying levels of sensitivity, precision, and deployment from fixed lab to field-deployable systems.

The accuracy of LIBS measurements is typically better than 10% and precision is often better than 5%. The detection limits for LIBS vary from one element to the next depending on the specimen type (matrix), the experimental apparatus used, and experimental conditions under which desired measurements are made. Even so, detection limits of 1 to 30 ppm (by mass) are common, with detection limits of < 1 ppm being observed.

System Components and Specifications

The backpack LIBS system consists of a small Nd:YAG laser (Kigre, Inc.) operating at 1/3 Hz with an output energy of 25 mJ in a 4-ns pulse. The emission from the plasma is collected with three Ocean Optics spectrometers (Model HR2000+) using optical fibers after a delay of 3 microseconds. The emission is detected with a CCD detector and analyzed with a small frame computer (Sony, Inc.).

Figure 1 depicts the backpack LIBS system along with labels indicating the major components. The system contains four major components: (A) the electronic control unit, (B) the data acquisition/control unit, (C) the sampling head, and (D) an umbilical cord that handles communication and power requirements for the system components. The electronic control unit, located in the backpack and labeled as A in Figure 1, consists of the laser power supply, Ocean Optics spectrometers, and associated electronics for controlling the system. A small frame personal computer (labeled B in Figure 1) serves as the master controller for the laser, electronics, spectral collection, and data analysis. The green and silver unit (labeled C in Figure 1) located at the end of the probe is the sampling head, which contains the laser and focusing optics used to generate the plasma. The black umbilical cord (labeled D in Figure 1) contains the cables for supplying power to the laser and fiber optic cables used for collecting emission from the plasma and directing it to the spectrometers. It also contains cables for communication between the computer and the Ocean Optics spectrometers and cabling between the digital delay generator and the computer. A complete list of system components and specifications is shown in Table 1.

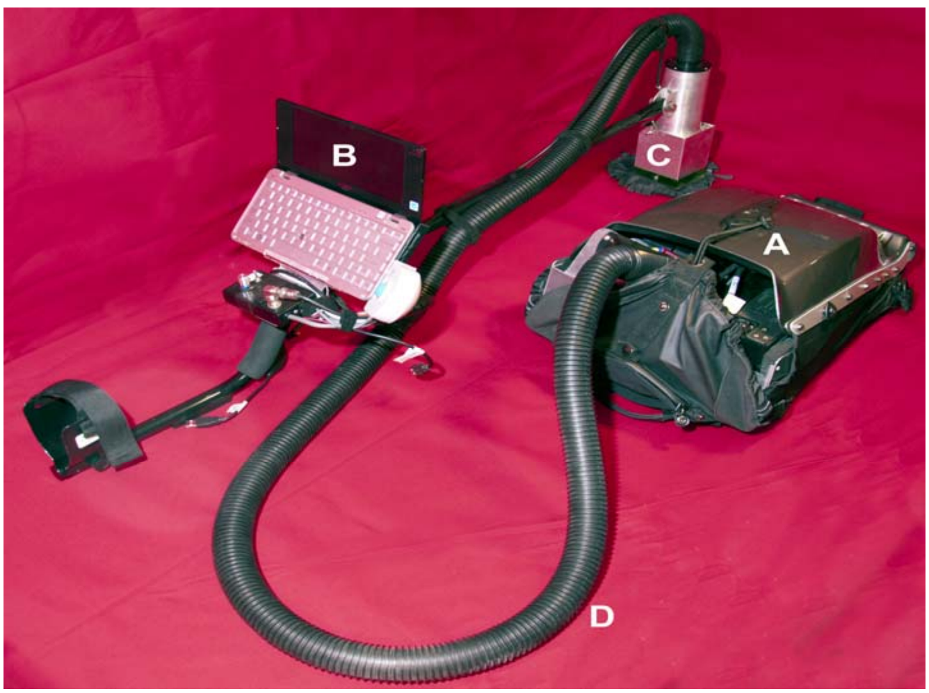

Figure 1. Photograph of the Backpack LIBS System

Table 1. System Components and Specifications

1.	Laser (Kigre, Inc.), nominal output 25 mJ / pulse single shot, pulse width 4 ns, beam diameter 3 mm, beam divergence 90% less than 1 mr, rep rate 1/3 Hz, lifetime > 300,000 shots
2.	Three spectrometers (Ocean Optics), HR2000+, spectral ranges UV (200-400 nm), VIS (400-600 nm), NIR (600-1000 nm), 2 MHz A/D converter, programmable electronics, a 2048-element CCD-array detector, high-speed USB 2.0 port, spectral resolution approximately 0.35 nm (FWHM)
3.	Four-port USB hub (D-link@ 4-Port USB 2.0 hub (HUB-H-4))
4.	Digital delay generator (Highland Technology), 4 pulse outputs, 5 V each, programmable for delay, width, and polarity, delay range 0 to 10 seconds, 10 ps resolution, and width range 2 ns to 10 seconds, 10 ps resolution, trigger rate 0 to 16 MHz
5.	Computer (Sony, Vaio P Series VGN-P699 E/Q), 533 MHz CPU, 2 GB RAM, 256 GB hard drive
6.	Collection fibers (Ocean Optics) trifurcated , 2 meters in length
7.	Focusing lens (CVI Optics)
8.	A power distribution system used to supply power to all of the electronic components in the electronic control unit and safety interlock systems

System Connectivity and Initial Setup Diagram

The backpack LIBS system can be shipped to a user or customer via two options. The first option is to have the system shipped unassembled. For this option, qualified personnel may refer to the connectivity diagram shown in Figure 2 for proper assembly. However, it is highly recommended that the user consult the developer of this system for guidance in the correct assembly of the backpack LIBS system.

The second option is to request that the system be shipped with approximately 90% of the components pre-assembled. In this case only a few connections must be made: (1) connect power cable to the computer, (2) connect the battery cable to the electronic control unit, (3) connect the battery power cable to the power supply for the laser, and (4) connect the USB cable to the computer after the computer has been booted up so that the Windows operating system can recognize the components connected through the USB cable and hub.

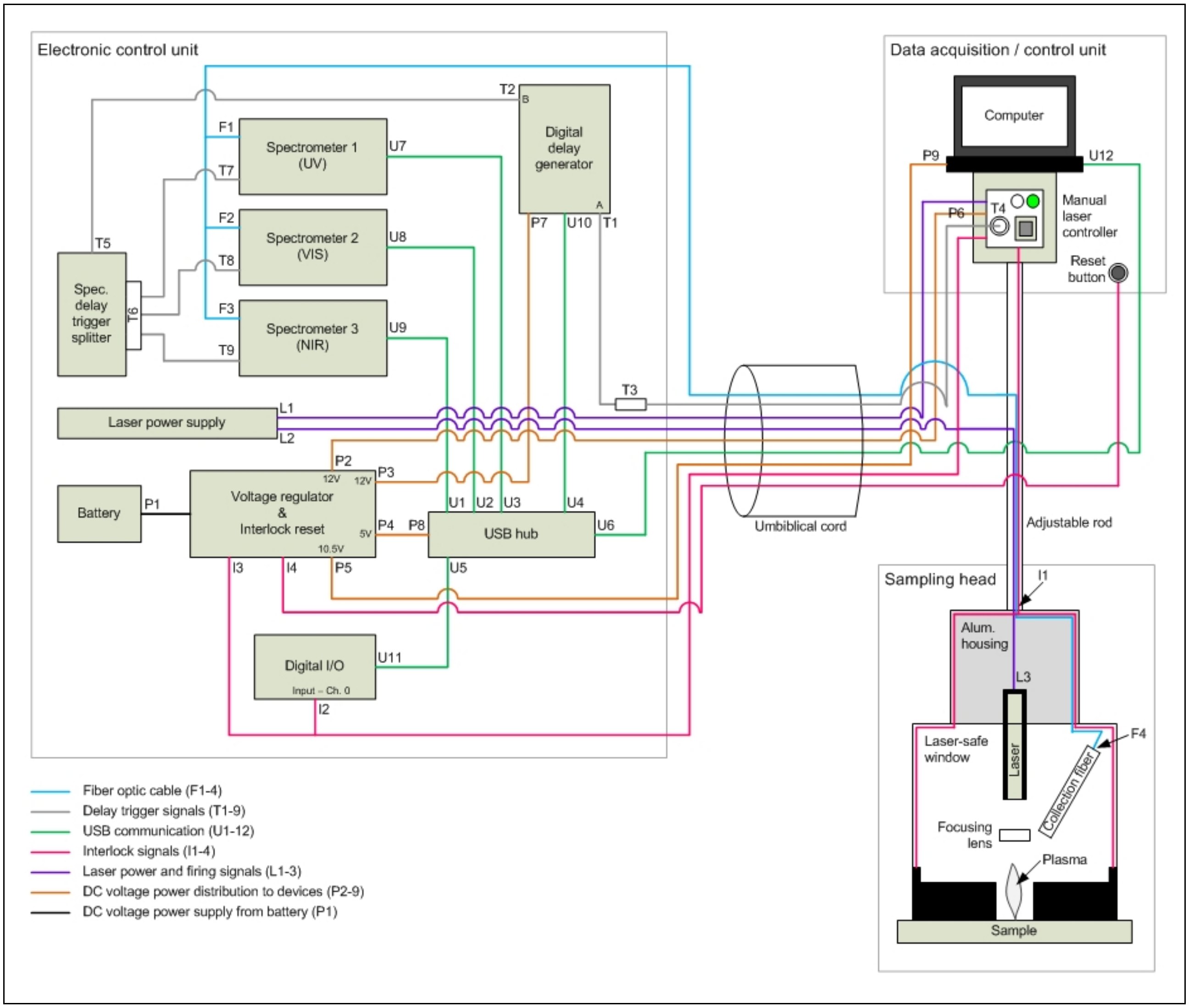

Figure 2. System Connectivity Diagram for the Backpack LIBS System

Operator Safety Considerations/Responsibilities

Under normal operating conditions, with both the software and hardware safety interlock systems fully engaged, no laser safety eyewear is required. However, the operator and personnel in the vicinity must be aware that exposure to the laser beam or the microplasma can cause serious skin or permanent eye damage without these controls in place. The ultimate responsibility for the safe use of this product lies with the operator, who must use the product within the integrated safety envelope of the backpack system as designed.

WARNING

Never attempt to use this system to analyze flammable liquids such as gasoline, ether, or explosive gas mixtures (for example, methane and air). This device uses the emission from a high-intensity laser-generated microplasma or spark to measure the elemental composition of samples of interest. The attempted use of this device to analyze the materials mentioned could result in serious injuries to the operator up to and including death. For analysis involving flammable liquids or explosive gas mixtures, contact the developer of this device, James E. Barefield II, 505-665-5195 or jbarefield@lanl.gov, for guidance.

Safety Systems

This product includes engineering controls, both software and hardware, ensuring that the operator can safely operate the system under normal conditions. The safety systems include:

- A "Ready" button on the main panel computer screen that is green if the software is ready to operate (that is, if the laser safety interlock is engaged and if communication with all of the associated devices has been established). If the laser safety interlock has been disengaged or if one or more of the devices are not present, then this button is red. In addition, a message will appear instructing the operator to check the laser safety interlock or hardware connections.
- There is also a mechanical reset button that must be pressed if the laser safety interlock has been disengaged. This prevents the laser from continuing to fire until the operator is ready to restart the desired analysis.
- The green enclosure located at the bottom of the sampling head has near-zero percent transmission at the fundamental wavelength (1064 nm) of the Nd:YAG excitation laser, thereby reducing the probability of the operator being exposed to the invisible laser beam above the MPE (maximum permissible exposure limit) and from the emission of the plasma.

Sampling and Analysis Guidelines

The backpack LIBS system utilizes advanced computer data acquisition, control, and analysis along with a compact laser, electronics, spectrometers, and optical equipment. The customers or users must develop methods of sample analysis unique to their own analysis requirements and experience. Our development team is available to assist the users or customers to help develop the desired skills required for their specific application. This user guide is intended for basic instructions in elemental analysis of samples.

Backpack LIBS System Operating Instructions

The LabVIEW program, LANL Portable LIBS.vi, is designed to control the operation of the backpack LIBS unit. The following operating instructions are divided into five major subsections: (A) main panel, (B) data acquisition and control device connectivity, (C) LIBS measurement and analysis, (D) display archived data, and (E) troubleshooting.

The main panel section outlines the basic functions and additional features in the LANL Portable LIBS.vi program. The data acquisition and control device connectivity section details the cabling that connects the devices in the electronic control unit, the data acquisition and control unit, and the sampling head (see Figure 2). The LIBS measurement and analysis section is a step-by-step procedure used to obtain spectral data, while the display archived data section shows how to open and view data previously saved. Finally, the troubleshooting section contains helpful tips for some typical problems that may arise during operation of the backpack LIBS system.

A. Main Panel (LANL Portable LIBS.vi)

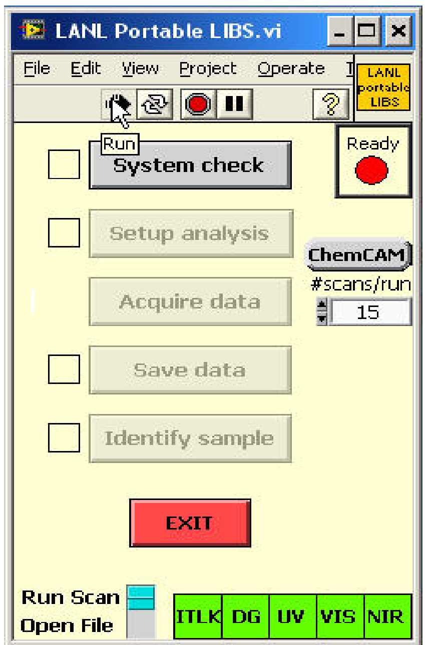

Figure 3. Main Panel (LabVIEW program LANL Portable LIBS.vi)

The LabVIEW program, "LANL Portable LIBS.vi" (Figure 3), is the executable control software used to operate the backpack LIBS unit; hence, it is also called the "main panel." Each functional button in this program, when activated, carries out a specific task, such as checking the system functionality, setting up analysis parameters, acquire spectral data, saving spectral data, and identifying samples from known spectral signatures located in a validated database. Additional objects are used to change the running mode and to indicate which data acquisition and control device(s) are found. Also, the additional objects are used to indicate if the backpack LIBS system is ready for analysis, to indicate whether or not a specific task is completed, and to stop running the main panel program. The main panel functional buttons and objects are outlined in A.1 and A.2.

A.1. Functional Buttons

System check	Verifies functionality of the LIBS system with initial checks against known standards
Setup analysis	Allows the user to inputs the number of shots to average per sample analysis
Acquire data	Acquires and displays LIBS emission spectral data
Save data	Saves spectral data
Identify sample	Identifies samples by comparing measured to known spectral data located in the validated database

A.2. Other Objects

EXIT	Stops the LANL Portable LIBS program
Run Scan/Open File	Selects the running mode: **Run Scan** Acquires spectral measurements **Open File** Displays archived spectral data
Indicator LEDs: **ITLK / DG / UV / VIS / NIR**	Indicates if specific data acquisition and control devices are present **ITLK** Red indicates the laser safety interlock is not latched Green indicates when the laser interlock is engaged **Others** Green indicates the device is present Background color or light yellow indicate the device is not detected
Ready LED	Indicates readiness of the backpack LIBS system: • Green indicates the laser safety interlock, digital delay generator, and spectrometers are all working • Red indicates one or more devices are missing
ChemCAM **and # scans/run**	For user-specific applications. Additional features may be added for use in other application(s).
Square boxes to the left of the functional buttons	"X" indicates if the corresponding task has been successfully completed.

B. Data Acquisition and Control Device Connectivity and Initial Start-up

Before running the main panel program, make the following cable and optical fiber connections for the data acquisition and control devices in the backpack LIBS unit:

B.1. Secure all connections

Secure all connections according to the backpack LIBS system connectivity diagram (Figure 2).

- Fiber optic cable leads (F1-4: spectrometers and fiber mount in the sampling head)
- Trigger signal connections (T1-9: digital delay generator, coaxial union inside electronic control unit, coaxial connection on manual laser controller, spectrometer delay trigger splitter, and spectrometers)
- USB cables (U1-12: USB hub, spectrometers, digital delay generator, and digital input/output module)
- Laser interlock signal (I1-4: sampling head, digital I/O module, and laser interlock reset button)
- Laser (L1-3: laser power supply and laser in the sampling head)
- DC power distribution (P2-9: voltage regulator, USB hub, digital delay generator, manual laser controller, and computer)

B.2. Connect fully charged battery to the electronic control unit

Place a fully charged battery in the electronic control unit (inside the backpack). Connect power cable (P1) between the battery and voltage regulator.

B.3. Log on to the computer and activate the LANL Portable LIBS.vi

Turn on the computer, log in, and double-click on the LANL Portable LIBS icon on the desktop.

B.4. Connect the USB cable between the hub and the computer

Connect the cable (U12) between the USB hub and the laptop. Click cancel on the pop-up window for the digital I/O module driver installation. There will be a few audible sounds while the computer recognizes the spectrometers and digital delay generator.

B.5. Turn on the manual laser controller

Toggle the ON/OFF switch on the manual laser controller to the ON position.

B.6. Engage laser safety interlock

Engage the laser safety interlock by placing the sampling head over the desired sample. Next, press the reset button located on the back of the data acquisition and control unit. The red LED will turn off on the manual laser controller and the green LED will then turn on, indicating the laser is ready to fire.

Repeat this step after changing out samples or whenever the sampling head is lifted, as this action causes the laser interlock to become disengaged.

C. LIBS Measurement and Analysis

Prior to performing LIBS data collection and analysis, the operator is required to perform a system check to verify that the backpack LIBS unit is operational. When the system check is complete, the software will automatically open the "Setup analysis" window, where the operator can enter the number of shots to average. After this step is complete, the "Acquire data" button will be enabled, which allows spectral emission to be obtained. The data can then be saved using the "Save data" function. Samples can be identified from the validated database using the "Identify sample" button by comparing the current spectral data to known data located in the validated database.

LIBS measurement and analysis is detailed in the next seven subsections: (1) Start Up, (2) System Check, (3) Setup Analysis, (4) Acquire Data, (5) Save Data, (6) Identify Sample, and (7) Shutdown.

Follow these step-by-step instructions to identify the sample(s) or perform analysis as desired. See the Troubleshooting section if problems are encountered.

C.1. Start Up

To begin analysis, select "Run Scan" mode (bottom left of the main panel) and then click on the "Run" arrow (top left of the main panel) as shown in Figure 3. This arrow, turning from open arrow to filled black arrow, is an indication that the LabVIEW program is running. The program verifies that all required devices are present (the laser interlock via the digital I/O, digital delay generator, and spectrometers). When all devices are found, the round "Ready" LED (top right) will turn green, while the bottom square LEDs (ITLK, DG, UV, VIS, and NIR) will change colors accordingly to indicate which devices are detected (green means device is detected). Table 2 shows the LED colors corresponding to the status of the data acquisition and control devices.

If communication between devices is severed, the "Ready" LED will turn red. Place the cursor on top of this LED to view a list of missing device(s) or look for the missing device(s) at the bottom of the main panel (see Table 2). When the laptop battery power falls below 25%, a message will notify the operator to swap out the battery in the electronic control unit (located inside the backpack).

Table 2. System Status Indicator Lights and Descriptions

Device	LED	Ready	Not ready/detected
All devices	Ready	Green	Red
Laser interlock (ITLK) and digital I/O	ITLK	Green	Red
Digital delay generator (DG)	DG	Green	Light yellow (background color)
Ultraviolet (UV) spectrometer	UV	Green	Light yellow (background color)
Visible (VIS) spectrometer	VIS	Green	Light yellow (background color)
Near infrared (NIR) spectrometer	NIR	Green	Light yellow (background color)

The analysis functions in the main panel must be carried out in sequence from top to bottom (see Figure 3). Each succeeding functional button will remain disabled (grayed out) until the task(s) above it has been successfully completed. When a function is activated, a new sub-window corresponding to that specific function will open. Note that the operator can return to the main panel by pressing the EXIT button from the sub-task window. The completion of each function (except "Acquire data") is indicated by an "X" in the box to the left of each function button.

The "System check" and "Setup analysis" tasks must be completed at least once prior to performing an analysis. The "Acquire data" function can then be repeated to obtain spectral measurements. Once the measured spectra are available, both "Save data" and "Identify sample" functions will be enabled. The operator can then save the spectral data and or identify a sample by comparing the measured to the known spectra in the validated database, if desired.

Make sure that the main panel "Ready" LED is green before performing any of the first three tasks (system check, setup analysis, and acquire data).

C.2. System Check

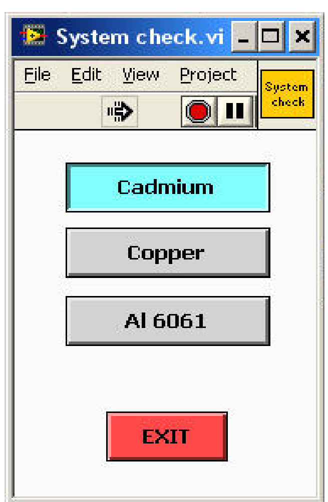

Figure 4. System Check window (for standard selection)

After pressing the “System check” button in the main panel, the main panel screen will disappear and the “System check” window will be activated. The “System check” window contains a selection of 3 standards: cadmium, copper, and aluminum 6061as seen in Figure 4.

Place the selected standard under the sampling head with the laser interlock engaged (see step B.6 in the data acquisition and control device connectivity section) before pressing the corresponding standard button in the “System check” window. Note that the standard samples can be selected in any order and the “System check” task is complete only when the emission spectra for all three standards are matched. Positive identification is indicated by an “X” in the square box to the left of the “System check” button in the main panel (see Figure 3). As each standard is matched, the corresponding sample button will become highlighted (light gray when not matched). Press EXIT at any time to return to the main panel.

After pressing the named sample button in the “System check” window, the “Standard check” window will become visible. The known spectrum of the selected standard from the database is displayed, in a maroon color, before emission is collected from five laser shots. The average of the collected emission spectra is then overlaid in blue color. Note that the countdown from five shots is displayed on the bottom right of the plot. Only the UV spectra are displayed here. In actual practice for all LIBS data collection and analysis, the VIS and NIR data channels are measured but not displayed in this “Standard check” plot.

Between shots, the software will verify that the laser interlock is engaged. If the laser interlock connection is lost, data acquisition will be discontinued and all data collected up to this point will be discarded. A warning message will appear, the “Standard check” window will be closed, and the “System check” window will be visible again. See troubleshooting subsection E.2 for help with re-engaging the laser interlock before re-starting the standard checks.

The operator is required to acknowledge whether or not the measured spectral data match the known spectra for each standard. Refer to Figures 5, 6, and 7 as a reference to confirm matching of the Cd, Cu, and Al 6061 spectra, respectively. If matched, the “Standard check” window is closed and the operator is returned to the “System check” window for selection of the next standard. If there is no match, a message will prompt the operator to verify that the correct standard has been placed under the sampling head.

Once the operator has completed the system check and all three spectral matches have been confirmed, pressing the EXIT button will return the operator to the main panel window, where an “X” will appear to the left of the “System check” button. This indicates that the system is operating properly and that the operator can proceed to the “Setup analysis” functional button to begin sample analysis.

The system check must be completed only once as long as the main panel remains open. However, if the LabVIEW program is restarted, the system check validation is voided and this task must be repeated.

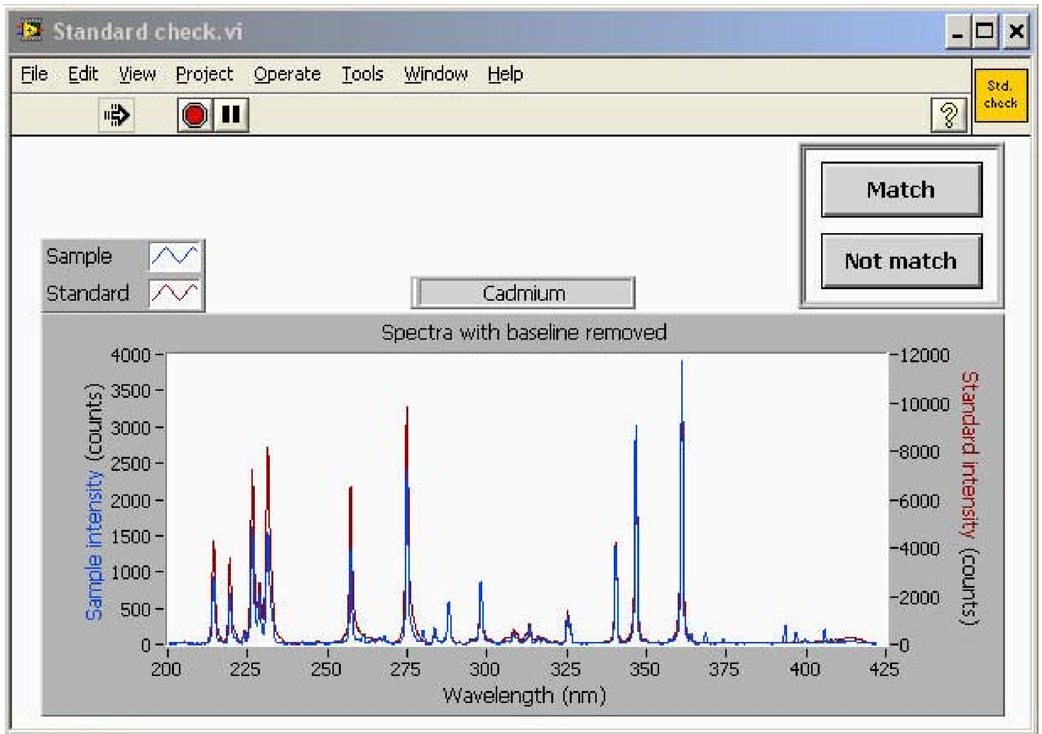

Figure 5. Cadmium Spectra

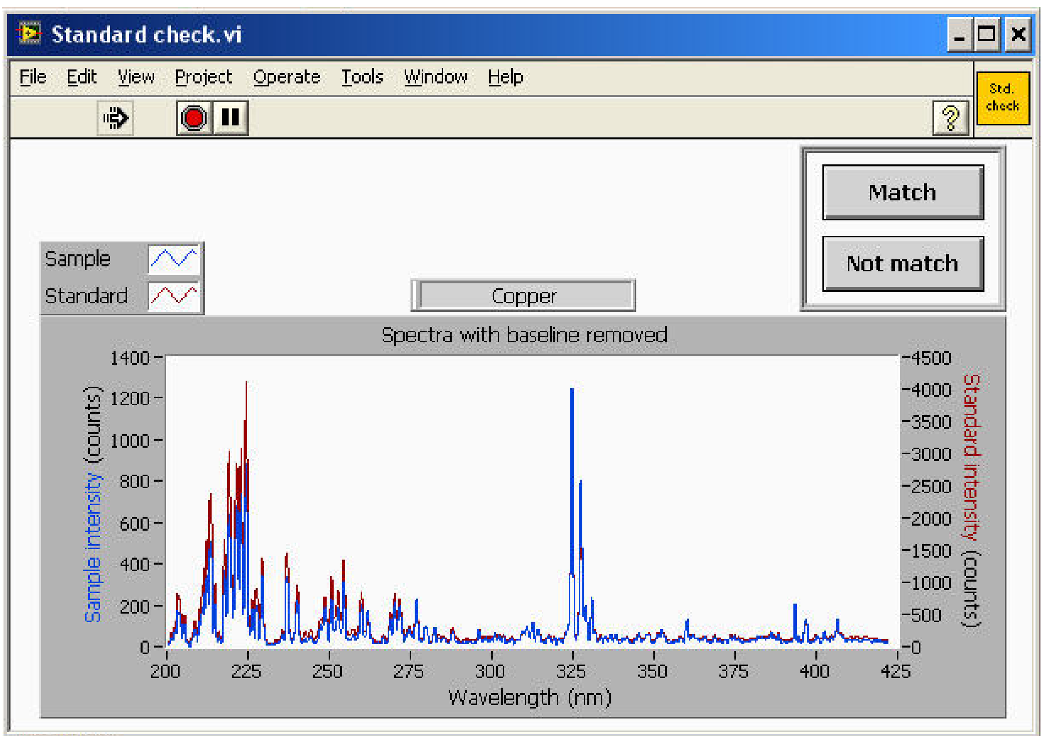

Figure 6. Copper Spectra

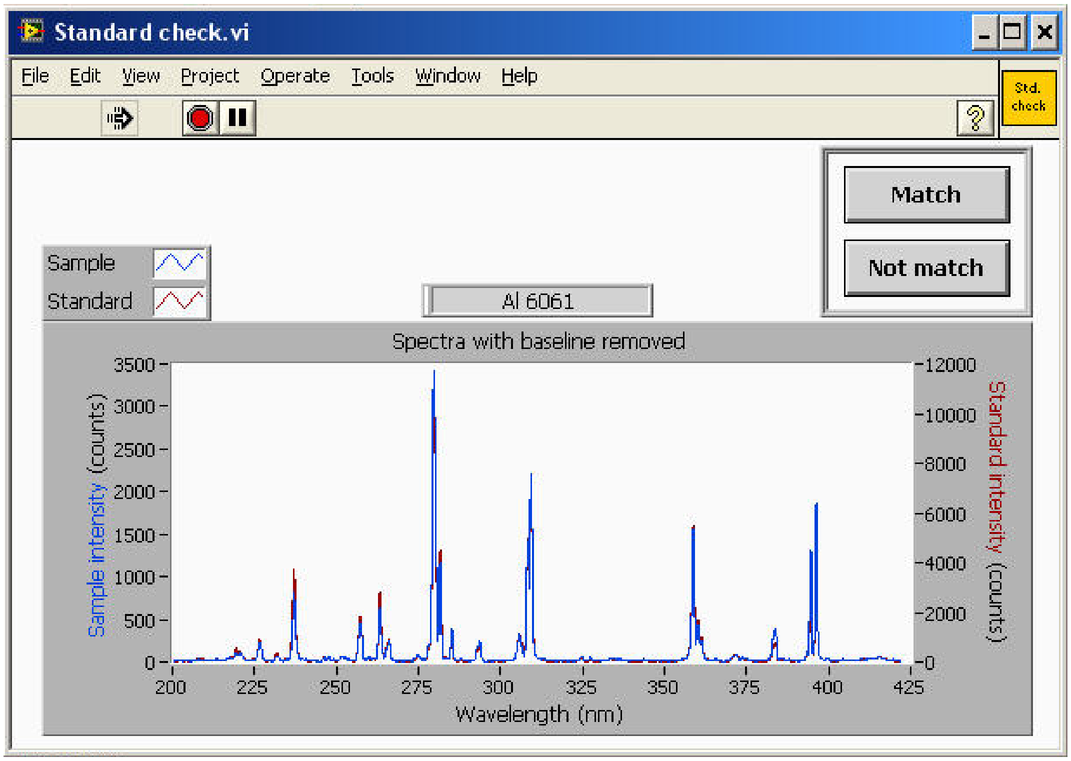

Figure 7. Al 6061 Spectra

C.3. Setup Analysis

When the "Setup analysis" function is activated in the main panel, the "Setup analysis" window (Figure 8) will become visible with the option to modify the number of laser shots per sample analysis. To access other choices besides the default five-shot scan (such as single-shot and multiple-shot scan), click on the down arrow on the right-hand side of the pull-down menu. For the single-shot scan, the number of shots is 1. For the five-shot scan (the default setting) the number of shots is 5. If the multiple-shot scan option is selected, enter the desired number of shots to the right of the scan selection. Press the "Setup analysis" button when ready. When the "Setup analysis" function is completed, the "Setup analysis" window will be closed automatically and the main panel window will open. An "X" is marked on the square box to the left of the "Setup analysis" button in the main panel window, indicating that the setup analysis is complete.

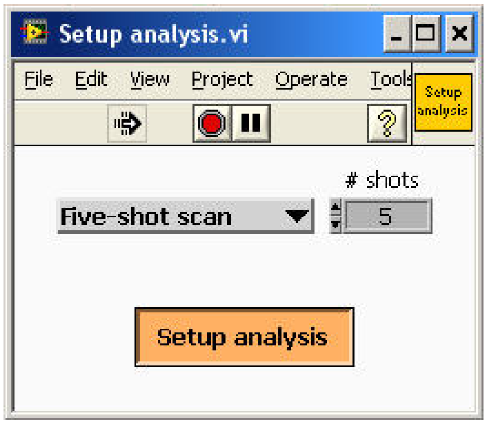

Figure 8. Setup Analysis window

C.4. Acquire Data

When the "Acquire data" function is selected in the main panel, a digital display appears to the left of the "Acquire data" button to show the countdown from the number of shots selected in the "Setup analysis" window. Between shots, the software will check for the laser interlock. If the laser interlock connection is lost, data acquisition will be stopped and all data obtained up to this point will be discarded. A warning message will appear, the "Ready" LED button will turn red, and all functional buttons will be grayed out (disabled) until the laser interlock is re-established. See troubleshooting subsection E.2 for help with re-engaging the laser interlock. The "Ready" LED button must turn green before the "Acquire data" function can be re-activated. Note that as long as the "Ready" LED color is red, all functional buttons remain inaccessible (grayed out).

After the desired number of spectra has been collected, the main panel window will close. The "Plot spectrographs" window (Figure 9) will become visible and the measured spectral data will be displayed. The "Plot spectrographs" window contains various plotting and task options, such as overlay or clear archived data, save data, and ID sample. When the "Remove baseline" square button is activated (green), the spectral data is baseline corrected. Conversely, the raw spectral data (intensity values originally acquired from the spectrometers) will be shown if this function is disabled (light gray).

Click on the "Overlay" button to select files and display archived data in the same plot as the measured spectra. Up to 8 spectra can be overlaid in this plot. Click on the "X" square box to clear all overlaid spectra. Note that if the overlaid spectra are not cleared before leaving the "Plot spectrographs" window, they will be re-displayed along with the newly measured spectra the next time this window is opened. Press EXIT to return to the main panel window.

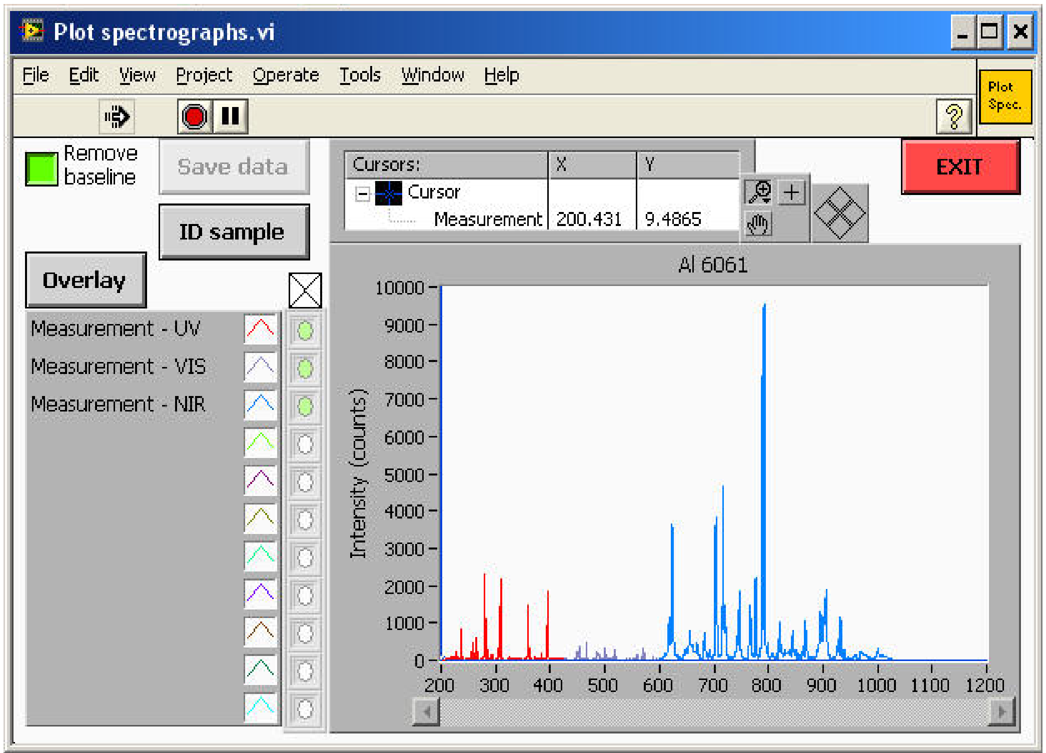

Figure 9. Acquire Data window

The "Acquire data" task can be repeated as many times as desired, after both system check and setup analysis are successfully completed. When the operator is satisfied with the quality of the spectra, he/she may choose to save the spectra and to identify the sample in this task window or in the main panel as described in the next two subsections (C.5 and C.6). When the spectral data are saved or the sample ID function is being activated in the "Plot spectrographs" window, the square box to the left of the corresponding functional button in the main panel window will be marked with an "X". This indicates that the particular task has already been completed.

C.5. Save Data

When the "Save data" window is activated (Figure 10), the sample name, when entered, will be saved in the operating parameter (COM) file. Data file naming will be automated with the following format, mmddyy_xx_zz.txt where

mm = month (2 digits)

dd = day of the month (2 digits)

yy = year (last 2 digits)

xx = file number index (increment by one each time the "Save data" function is activated)

zz = file name addendum denoting file content, where zz=UV, VIS, NIR, ALL, or COM

txt = file extension (text-formatted data, typically with data columns delimited by a tab)

After pressing the "Save data" button, five files will be generated: four are spectral data files (zz=UV, VIS, NIR, ALL) and the fifth file (zz=COM) stores the LIBS analysis operating parameters. Note that when using spectrometers for other applications, the file name addendum (UV, VIS, and NIR) will be replaced with S1, S2, and S3 corresponding to spectral data collection from spectrometers with the lowest to highest wavelength range, respectively. See Table 3 below for more details on the content of each file.

Table 3. Data Files Description and Content

File name addendum	File description	File content
COM	Operating parameters	Operating parameters
ALL	Data from all spectrometers	One or more pairs of wavelength* and intensity* with tab-delimit(s), depending on the number of spectrometers present at the time of measurement
UV (or S1)	Data from UV or first spectrometer	A pair of wavelength* and intensity*, tab-delimited, for the ultraviolet region (200 – 400 nm)
VIS (or S2)	Data from VIS or second spectrometer	A pair of wavelength* and intensity*, tab-delimited, for the visible region (400 – 600 nm)
NIR (or S3)	Data from NIR or third spectrometer	A pair of wavelength* and intensity*, tab-delimited, for the near infra-red region (600 – 1000 nm)

* wavelength in nm; intensity in counts

When the data saving task is complete, the file name, without the file name addendum and extension, will be displayed. The square box to the right of the file name will be marked with an "X". This indicates that data has been saved in text file format. The "Save data" window will be closed and the operator will be returned to the main panel window. An "X" will appear in the square box to the left of the "Save data" button in the main panel, indicating that the current spectral data has been saved.

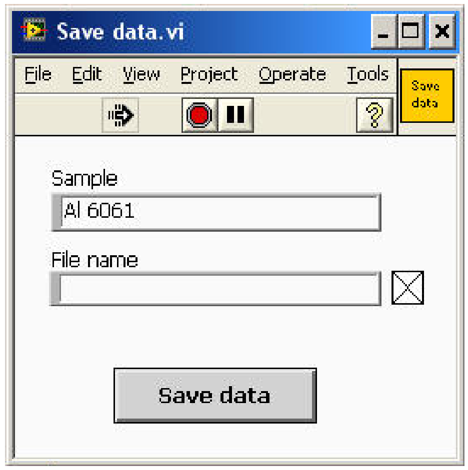

Figure 10. Save Data window

C.6. Identify Sample

After the current spectral data has been saved, clicking on the "Identify sample" button in the main panel will activate the "ID" window. The sample name will appear along with best scores, % of maximum score, and best matches. The best scores indicate how well the current spectral data matches the data stored in the validated spectral database. The best matches are arranged from highest to lowest % of maximum score. In Figure11, the current sample is Al 6061. The best match is Al 6061 as indicated by a % of maximum score of 100. When done, press EXIT to return to the main panel.

The operator also has the option of identifying samples from spectral data previously stored as described in subsection D. From the main panel window, click the "Open File" button and highlight the sample spectral data of interest. Click the "Acquire data" button to retrieve the data from the archive. The "Identify data" button will become active. The sample can be identified as described above. Again, when done press the EXIT button to return to the main panel.

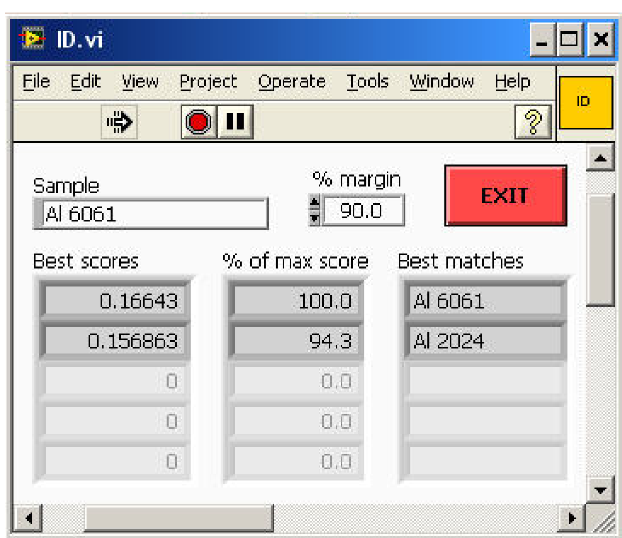

Figure 11. ID window (Identify sample)

C.7. Shutdown

Press EXIT at any time to stop running the main panel program (Figure 12). This is usually done at the end of LIBS analysis or when swapping out the battery in the electronic control unit. The "Run" arrow (top left) will turn from dark to clear, indicating that the LabVIEW program execution has ended.

Follow these steps to safely disconnect and turn off the backpack LIBS data acquisition and control devices:

1. Turn off the manual laser controller by toggling the on/off switch to the OFF position.
2. Disconnect the USB cable (U12) between the hub and the computer.
3. Disconnect the battery power cable (P1). Remove the depleted battery from the electronic control unit (inside the backpack) for charging.
4. Stop the LabVIEW application by selecting Exit from the File menu. Turn off the computer.

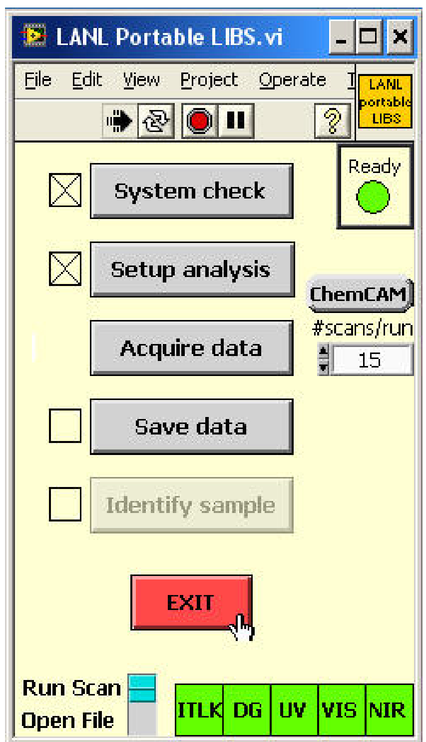

Figure 12. Shutdown

D. Display Archived Data

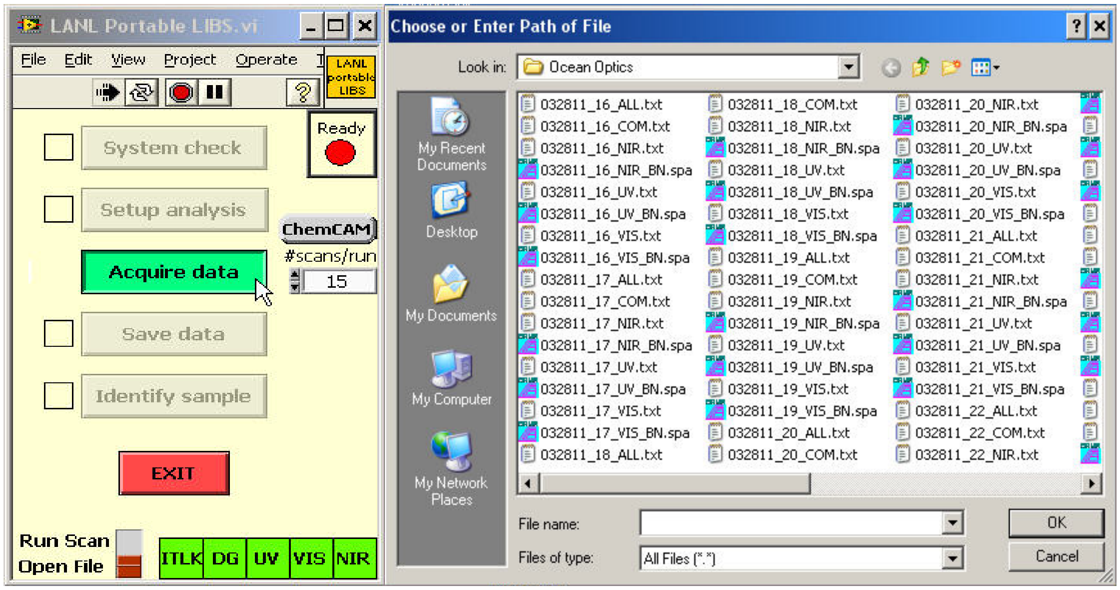

Figure 13. Open File window

To display archived data, open the main panel window. Select "Open File" on the bottom left (Figures 13 and 3). Click on the "Run" arrow to begin retrieval of archived data. This arrow, turning from clear to black, is an indication that the LabVIEW program is running. Most functional buttons are disabled or grayed out, except for the "Acquire data" function, which allows review of the saved spectral data using the LabVIEW plotting tool. When this function is activated, a file select window (labeled "choose or enter path or file" (Figure13)) is used to retrieve the desired data file. Refer to the Save Data subsection C.5 of the LIBS measurement and analysis for appropriate file names. Select a file for a given date. All 5 spectral data files for a sample of interest will be retrieved. The "Plot spectrographs" window (Figure 9) is then used to display the archived data. The "Save data" function is disabled to prevent the original data from being modified or overwritten.

When the "Remove baseline" button (top left of Figure 9) is activated (green), the spectral data will be plotted with the baseline removed. Conversely, the raw spectral data (original intensity data from the spectrometers) will be shown if this function is disabled (light gray). Click on the "Overlay" button to select files (see Save Data subsection C.5 for the backpack LIBS file naming convention) and to display archived data in the same plot as the current loaded spectral data. Up to 8 spectra can be overlaid in this plot. Click on the "X" square box to clear all overlaid spectra. Note that if the overlaid spectra are not cleared before leaving the "Plot spectrographs" window, they will be re-displayed along with the newly selected spectra the next time this window is open. Press EXIT to return to the main panel.

From the main panel, use the "Acquire data" button to select and display archived data from the backpack LIBS unit analysis operation. This can be repeated as many times as desired. Press EXIT any time to stop running the main panel program. A logic diagram indicating detailed procedures for making LIBS measurements using the backpack LIBS system is shown in Figure 14.

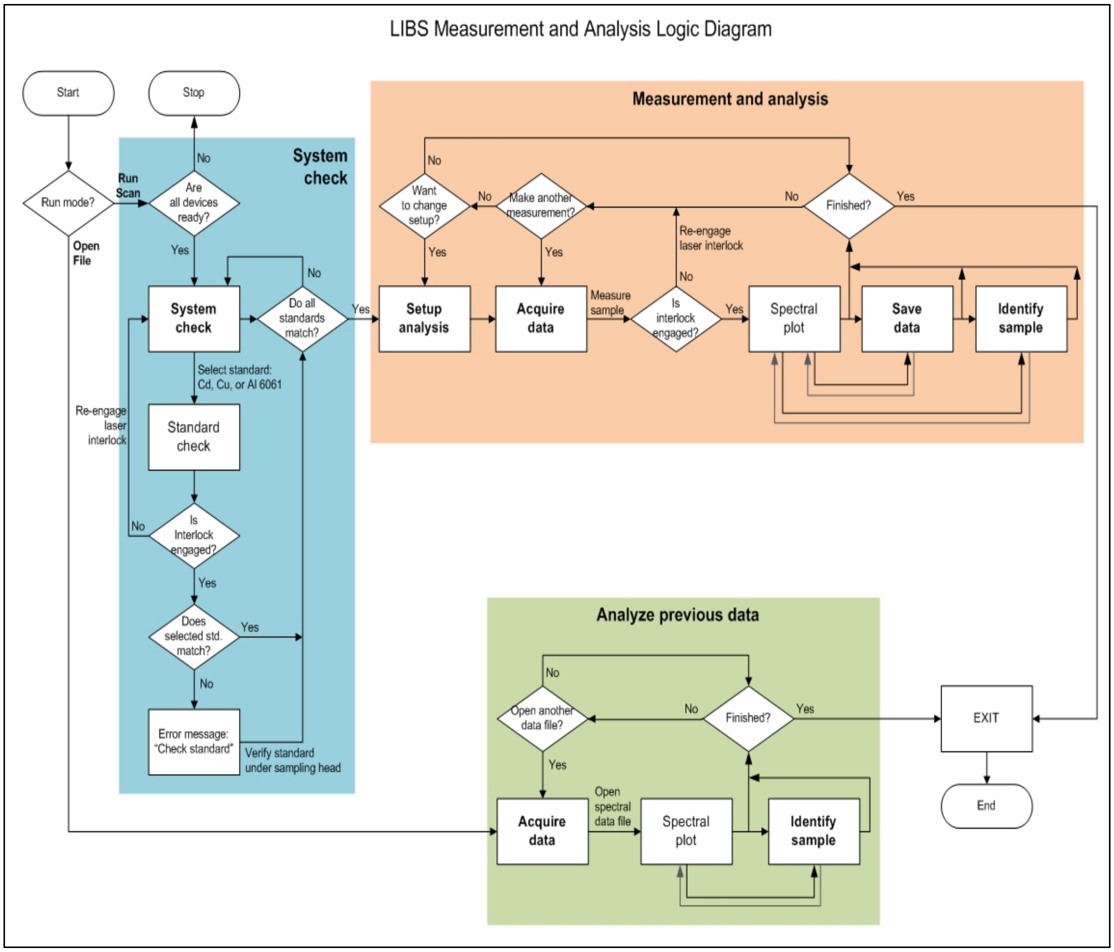

Figure 14. LIBS Measurement and Analysis Logic Diagram

E. Troubleshooting

The following are helpful tips for some typical problems that may arise during operation of the backpack LIBS system.

E.1 None of the devices are detected

There are two main causes for the backpack LIBS data acquisition and control devices (spectrometers, digital delay generator, and digital I/O) not being detected : (1) no or inadequate power being supplied by the battery in the electronic control unit or (2) the USB cable between the hub and the computer is disconnected. A "check battery power/cable and USB cables" message will appear as shown in Figure 15a. Click OK to close the warning window and stop the main panel program. Perform the following steps:

1. Turn off the LabVIEW application by selecting Exit under the File menu.
2. Disconnect the USB cable (U12) between the hub and the computer.

3. Check the battery. If the voltage is less than 60% of maximum capacity, replace the battery with one that is fully charged. Reconnect the power cable (P1) between the battery and the voltage regulator.
4. Reconnect the USB cable (U12). Wait for the audible sounds indicating that the computer recognizes the spectrometers, digital I/O for the interlock, and the digital delay generator.
5. Verify the device cabling as described in the data acquisition and control device connectivity section B.
6. Restart the program by double-clicking on the LANL Portable LIBS icon on the desktop. Restart the system by performing the procedure listed in section C (LIBS Measurement and Analysis).

E.2. Laser safety interlock failure

When the laser safety interlock is disengaged, caused by a slight lifting of the sampling head, an "interlock failed" message will appear as shown in Figure 15b. Click OK to close the warning window. Re-engage the laser interlock by repeating step B.6 of the data acquisition and control device connectivity section. Make sure the "Ready" LED on the top right turns green before proceeding with analysis using the backpack LIBS analysis system.

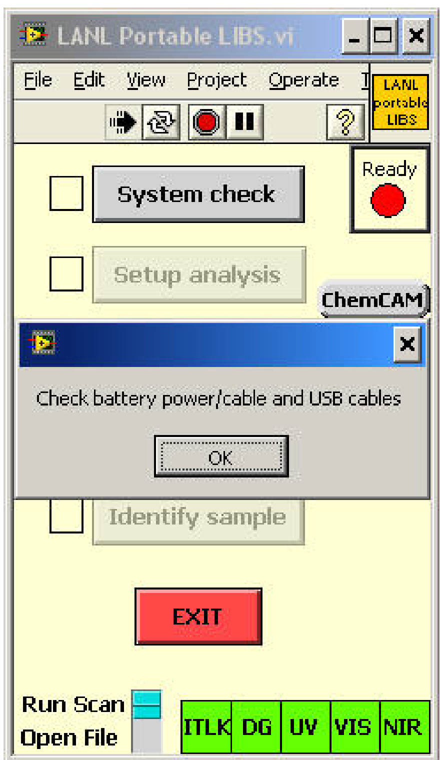

Figure 15a. No Device Detected

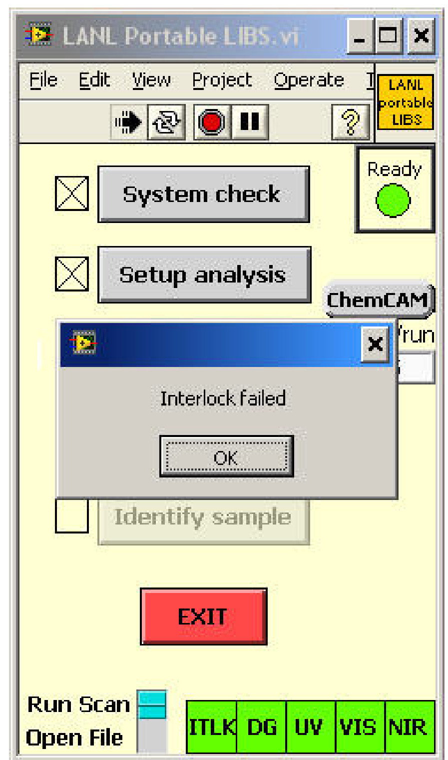

Figure 15b. Loss of Laser Interlock

E.3. Both LEDs on the manual laser controller are off

If this happens, power is not being supplied to the manual laser controller. Verify the following:

1. The DC power cables are connected (between the battery and voltage regulator, P1 and 12 VDC power between the voltage regulator and the manual laser controller, P2 and P6).
2. The power switch on the manual laser controller is in the ON position.
3. The laser interlock is engaged by pushing the sampling head firmly down over the sample.
4. Push the reset button behind the data acquisition/control unit.

Table 4. Troubleshooting

Problem	Probable cause(s)	Suggested solution(s)
No device detected	1. Low system battery or the battery is not connected to the voltage regulator box. 2. USB device hub is not connected to the computer.	1. Check voltage on battery. Install or replace with fully charged battery if necessary. Connect power cable P1. 2. Connect USB cable U12 and wait for the devices to be recognized by the computer (listen for audible sounds).
1. Interlock failed 2. Functional buttons are disabled (appearing nearly transparent)	Laser interlock switches at the bottom of the sampling head are disengaged.	1. Check interlock switches on the bottom of the sampling head. 2. Press down on the sampling head to reengage the laser safety interlock. 3. Press the reset button to activate laser power. 4. Re-start the LabVIEW program and follow the procedure for start up. Check if the functional buttons are enabled and "Ready" LED turns green. See Table 2 for descriptions of the functional buttons and indicator lights.
Both LEDs on manual laser controller are off	No power to the laser.	1. Check power source at P1, P2, and P6. 2. Press the reset button to activate laser power.
"Acquire data" function starts but laser shot countdown pauses	1. Power cable P7 to the delay generator may have come loose. 2. Low system battery.	1. Secure power cable P7 connection. 2. Check voltage on battery. Replace with fully charged battery. Connect power cable P1. 3. Restart the LabVIEW program and follow the procedure for start up.

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